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RESEARCH PAPER

Physical activity monitoring in stroke: SenseWear Pro2 Activity accelerometer versus Yamax Digi-Walker SW-200 Pedometer

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Abstract

Purpose: Determine validity and reliability of SenseWear Pro2 Armband (SWP2A) and Yamax Digi-Walker SW-200 Pedometer (YDWP) in stroke and healthy adults. *Methods*: Fifteen stroke patients and 15 healthy participants wore SWP2A on upper arm and YDWP at hip/knee. Different activities were performed: treadmill walking, walking up/down a step, cycling and walking on an even surface. Steps and Energy Expenditure (EE) were measured and compared to steps counted manually and indirect calorimetry. Repeated measurements were compared to determine reliability of both devices. *Results*: Spearman correlation coefficients between knee-worn YDWP and counted steps while walking on an even surface was $\geq$0.89 in healthy and $\geq$0.95 in stroke. Treadmill walking revealed high Spearman correlation coefficients in healthy individuals ($r_s \geq 0.90$) and at 1.5 km/h in stroke ($r_s = 0.69$). During other activities YDWP often underestimated steps. SWP2A data revealed inconsistent results in EE and steps. Reliability tested by repeated measurements varied between 0.66 and 0.98 for YDWP and 0.61 and 0.97 for SWP2A. *Conclusion*: YDWP and SWP2A are both reliable. Only knee-worn YDWP is a valid device to measure steps except high intensity walking in stroke. YDWP systematically undercounts steps during other activities of short duration. This study could not demonstrate valid measurement of steps/EE in stroke using SWP2A.

Keywords

Ambulatory monitoring, energy expenditure, step activity, stroke

History

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➤ Implications for Rehabilitation

- Stroke is a disabling disease with residual neurologic deficits, which impairs mobility and predisposes them to sedentary behavior.
- A Yamax Digi-Walker SW-200 knee-worn pedometer showed to be a valid and reliable technique to measure ambulatory activity in stroke.
- A valid instrument to measure energy expenditure in stroke needs to be explored.

Introduction

Promoting daily physical activity after stroke is found to be important and supported by clinical guidelines [1–3]. After an insult, many stroke patients are faced with residual neurologic deficits, which impair mobility and predispose them to sedentary life style, resulting in cardiovascular and metabolic deconditioning, muscle weakness, increased intramuscular fat and gait impairment [4–7]. As a result stroke patients suffer an increased risk for recurrent stroke and cardiac death [8]. Increasing daily physical activity is therefore a major goal in secondary stroke prevention [9,10].

A variety of portable devices, including accelerometers and pedometers, have been used to determine physical activity [11,12]. These devices measure energy expenditure and/or ambulatory effort. Accelerometers tend to underestimate the activity level when the person is cycling, carrying goods or walking uphill. They also tend to detect more ''non-steps'' (an artifact corresponding to inexistent activity) than pedometers, typically under travelling conditions, in which vibrations of the vehicle are registered as movement [13]. In stroke patients, hemiparetic gait disturbance with associated weakness, spasticity and abnormal central neural patterning of muscle activation caused unreliable recordings by similar devices [14,15]. In stroke, there is still need for accurate devices to measure physical activity. The SenseWear Pro2 Armband (SWP2A) is an example of an accelerometer-based activity monitor that is worn at the

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upper limb and might be therefore less susceptible to measurement errors in stroke. The SWP2A is a portable device that monitors various physiological parameters (heat flux, skin temperature, galvanic skin response at near-body temperature) and movement (bi-axial accelerometer). This portable multisensory armband has been used to measure physical activity in healthy participants [16], diabetes [16], cystic fibrosis [17] and chronic obstructive pulmonary disease patients [18,19]. The estimation of free-living energy expenditure has recently been validated in 50 participants (healthy and diabetic) compared to metabolic activity measured by doubly-labeled water [16]. In stroke patients, however, the validity and reliability has not yet been studied. It is also unknown whether the portable armband is equally accurate when worn at the hemiplegic side in stroke patients. Whereas the SW2PA is worn on the arm, hemiparetic gait disturbances might have no influence. This could improve the accuracy. The developer's manual requires the SW2PA to be worn on the right arm. Hence, there is a clear need to determine if the SW2PA is a clinically useful tool to monitor the intensity of physical activity in stroke patients.

A simple and inexpensive device which is frequently used to measure physical activity in healthy participants is a pedometer [20,21]. This device registers the number of steps, but even in healthy participants belt-worn conventional pedometers vary in accuracy under different walking speeds and test conditions [22,23]. The reliability of the Yamax Digi-Walker SW-200 (YDWP) pedometer was demonstrated as acceptable to use for research goals in comparison to other spring-levered pedometers [11]. The YDWP clipped on the belt might work less accurate at slow walking speeds, because at low velocity the accelerations at the hip are not sufficiently large to be registered [21,23]. When the YDWP was placed on the hip, the mechanism of the pedometer showed insufficient sensitivity in slow walking [21]. In a stroke population, a device called StepWatch Step Activity Monitor, a microprocessor-linked step activity monitor, attached at the non-paretic ankle revealed to be a more reliable method in measuring steps in hemiparetic gait than a belt-worn pedometer [14]. However, a StepWatch Step Activity Monitor device is expensive and less clinically useful because of its placement on the ankle. Stroke patients often wear high orthopedic shoes at both sides and therefore placement of the device is not standardized. Therefore it is relevant to investigate if in stroke patients a knee-worn spring-levered pedometer registers the number of steps better than a belt-worn pedometer.

In summary, there is still need to search for valid and reliable devices in determining physical activity after stroke. The aim of this study is to examine the validity and the reliability of the SWP2A and a knee-worn YDWP in measuring number of steps and energy expenditure. Both devices are compared with standardized methods (indirect calorimetry and manual counting) under controlled conditions in stroke patients and healthy participants.

Methods

Participants

The sample size of 15 participants in each group was calculated prior to the study based on an expected Spearman correlation coefficient >0.80 as an acceptable correlation with a significance of $p < 0.05$ and a power of 0.80. Recruitment of 15 stroke patients was conducted by telephone calls with physiotherapists working in private practices in the provinces of Antwerp and Flemish Brabant in Belgium. Patients provided informed consent during home visits. Healthy participants ($N = 15$) were individually age- and gender-matched to the patient group and were related to patients or researchers. Patients and healthy participants were included if they were under 80 years old and had sufficient cognitive abilities to understand the instructions. A diagnosis of stroke was warranted as defined by the World Health Organization [24], at least 3-month post-stroke and a score >3 on the Functional Ambulation Categories (ability to walk with or without a walking aid or orthosis) [25]. Patients can also be included when motor function was unaffected; healthy participants may not have walking disabilities. Patients and healthy participants were excluded if they had medical problems that would preclude exercise testing as described by the American College of Cardiology Foundation/American Heart Association [26].

So 19 stroke patients were screened, of whom 15 were enrolled and completed the study. Reasons for exclusion included cardiovascular instability ($n = 1$) and scheduled planned surgical intervention ($n = 1$). Two other patients were excluded because of a low score on the Functional Ambulation Categories. Fifteen healthy participants were also included, age and gender matched to the patient group.

The protocol was reviewed and approved by the Medical Ethics Committee of the Antwerp University Hospital, Belgium (no. B30020084905). All participants provided written informed consent before the study.

Test procedure

For both groups of participants, the following measurements were taken or recorded at the home situation: age, gender, weight, height, hemiplegic side, handedness (using the Edinburgh Handedness Inventory [27]) and the level of mobility-related disability (using the Rivermead Motor Assessment of Gross Function, 0–13 scale, a high score equals minimal impairment [28]). After this baseline assessment, the experiment was performed in hospital so a test battery of activities under controlled conditions could be fulfilled. Activities to be performed were chosen to simulate functional activities: (1) treadmill walking (walking), (2) walking up and down a step (climbing stairs), (3) cycling on ergometer (cycling) and (4) walking on an even surface (free-living walking).

Validity was examined by comparing the number of steps registered by YDWS/SWP2A with the number of steps counted with a hand tally counter; EE was measured with SWP2A and compared to indirect calorimetry. To determine the reliability of both devices repeated measurements on treadmill and bike were compared for the number of steps and EE.

Number of steps measured

The Yamax Digi-Walker SW-200 (Yamasa Tokei Keiki Co. Ltd, Japan) is a uni-axial spring-levered pedometer and measures the number of steps. In healthy participants, a pedometer was worn on the anterior side of the hip and the anterolateral side of the knee on the right side. In stroke patients, the pedometers were placed on the hip and knee of the non-hemiplegic side. At the hip the pedometer was placed on a belt and at the knee attached to a patella support strap (S300 Aptonia knee strap). The YDWP counts individual steps.

The SenseWear Pro2 Armband (Health Wear BodyMedia, Pittsburgh, PA) was used to determine the number of steps. The SWP2A was worn on both upper arms and positioned on the triceps muscle halfway between the acromion and the olecranon. The SWP2A is programmed with a computer interface taking into account the participants personal data (age, gender, height, weight, smoking habit and handedness) prior to testing. Using specific software (Bodymedia, Sense Wear 6.1) the data are converted into number of steps by a proprietary algorithm. The number of steps obtained by the YDWP and SWP2A were compared with the number of strides counted manually by two researchers using a manual tally counter. To allow comparison with the pedometer results, the number of counted strides was multiplied by 2. For later reference, each activity was video recorded with a digital camera so that the number of steps was monitored. This video footage was used when both researchers counted a different number of steps in order to achieve consensus.

Energy expenditure measured

The SWP2A was also used to assess EE by a proprietary algorithm. The data are stored per minute. The beginning and end of an activity is indicated by a digital time stamp, in order to facilitate data analysis.

Indirect calorimetry using O_2/CO_2 analysis (CardioVit CS-200 Ergo-Spiro, Schiller) was used as criterion standard to compare the results of energy expenditure values given by the SWP2A. Ergospirometry took place in all activities except while walking on a flat level surface, because the device was not portable.

Ergospirometry is a valid and reliable method for measuring oxygen consumption and cardiovascular fitness during walking, cycling and treadmill testing in stroke patients [29]. The participant's nose and mouth were covered by a mask, which was connected to a computerized measuring device. After each activity, a print was made. Only the inhaled oxygen (VO_2) values were used and converted to energy expenditure per 10 second intervals as measured by breath-by-breath analysis. From these six values, an average was calculated, so the data per minute could be compared with the single outcome parameter per minute of the SWP2A.

Measurement protocol

The protocol consisted of a number of single, short-time activities which were carried out in the same sequence as described in Table 1, to examine validity of pedometer and accelerometer. To determine the reliability of both devices some activities on treadmill and bike are repeated. Participants were seated between activities until the heart rate descended to resting heart rate plus 20%, so the participants were recovered from previous activities.

First, measurements were taken with the participant lying down, standing and sitting, each activity lasting 3 min. Then the participant was invited to walk on the treadmill at speeds of 1.5 km/h (0.93 mph), 3 km/h (1.86 mph) and 3 km/h with a 5% slope. Walking at 1.5 and 3 km/h was then repeated. Afterwards, the participants walked up and down a step to a rhythm indicated by a metronome: sequentially 10 and 20 beats/min. Afterwards they were asked to cycle at 30, 50 and 65 W, each at 50 rpm. Cycling at 30 and 50 W was repeated. Every activity on the treadmill, step and cycle ergometer lasted for 4 min. Finally participants were asked to walk a self-selected walking speed on a flat level surface, once at normal and once at brisk walking speed. Participants were first instructed to walk on a flat level surface for a length of 120 m. The participants were told that the first speed should be typical of their normal everyday walking speed. The second time they were asked to walk as fast as possible, while remaining within safe limits. Counting the number of steps was executed during all activities except while cycling.

Table 1. Activity protocol.

Activity	Duration (min)	Intensity
Lying down	3	–
Standing	3	–
Sitting	3	–
Treadmill	4	1.5 km/h*
		3 km/h*
		3 km/h + 5% slope
Step up and down	4	10 steps per min
		20 steps per min
Cycling	4	30 W*
		50 W*
		65 W
Walking	120 (duration depending on walking speed)	Normal walking speed
		Brisk walking speed

*Two repeated measurements.

Statistical analysis

All statistical analyses were performed using SPSS (version 20.0, SPSS Inc, Chicago, IL). Descriptive statistics of participant characteristics were calculated. Normality was verified with the Kolmogorov–Smirnoff test. Since the data were mostly not normally distributed non-parametric statistics were used to analyze the data. A Spearman correlation coefficient (r_s) was calculated to determine the level of association between the pedometer versus counted steps (steps) and accelerometer versus indirect calorimetry (energy expenditure). A Spearman correlation of 0.5–0.70 was considered a moderate correlation, 0.70–0.90 as a good to high correlation, >0.90 was considered as an excellent correlation [30]. Statistical significance was set at $p < 0.05$. To visualize the level of agreement between the experimental device (YDWP, SWP2A) and the criterion standard (counted steps, indirect calorimetry) a Bland–Altman Plot was used [31]. In the Bland–Altman Plot, the criterion standard measures were plotted against the difference between both measures to give an indication of agreement between the two methods of measurement. This also provides a 95% confidence interval based on the calculated standard deviation of the differences. To determine the test–retest reliability, two-way mixed intra-class correlation coefficients with single measures were calculated. An intra-class correlation coefficient between 0.40 and 0.59 was withheld as a fair correlation, 0.60 and 0.74 as a good correlation and $\geq$0.75 as excellent [32].

Results

Participants

The demographic and clinical characteristics of included participants are presented in Table 2. Fifteen patients with a mean age of 60.40 years ($\pm$10.26) and mean time since stroke 6.20 years ($\pm$05.08) participated. Fifteen healthy participants (mean age 58.07 years $\pm$10.37) were included.

Table 3 shows the number of steps measured by YDWP, SWP2A and criterion standard while walking on a flat level surface at two different speeds in stroke and healthy adults. In stroke patients, only seven patients (50%) could walk without walking aids or orthosis, four patients (28.6%) needed a cane, one patient (7.1%) wore an ankle foot orthosis (AFO) and two patients (14.3%) used a cane and AFO at two different walking speeds. One patient could not walk the entirely 120 m distance, because of a knee prosthesis. In healthy adults, no walking aids or orthosis were used.

Number of steps measured: validity

Table 4 summarizes the association (Spearman correlation coefficient) between the manually counted steps and the steps measured with the pedometer worn on the hip and knee and with both SWP2A (worn on left and right arm). When the intensity became more strenuous, less participants could fulfill the different activities. Each activity was separately analyzed. There were high to excellent correlations found between the pedometer worn on

Table 2. Demographic and clinical characteristics of participants.

Characteristics	Stroke ($n = 15$)	Healthy ($n = 15$)
Age, mean (years) ±SD	60.40 ± 10.26	58.07 ± 10.37
Gender female, n (%)	6 (40.0)	10 (66.7)
Height, mean (m) ±SD	1.69 ± 00.08	1.69 ± 00.09
Weight, mean (kg) ±SD	82.40 ± 09.62	84.33 ± 19.62
BMI, mean (kg/m^2) ±SD	28.87 ± 03.49	29.39 ± 06.39
Time since stroke, mean (years) ±SD	6.20 ± 05.08	
Stroke type		
Ischemic, n (%)	5 (33.3)	
Hemorrhagic, n (%)	6 (40.0)	
Both, n (%)	4 (26.7)	
Side of hemiparesis		
Left, n (%)	9 (60.0)	
Disability stroke		
RMA-GF, median (IQR)	11 (0.0)	
FAC, median (IQR)	4 (1.0)	
Mobility		
No use of walking aids in ADL, n (%)	7 (46.7)	15 (100.0)
Experience with walking on treadmill, n (%)	8 (53.3)	4 (26.7)
Handedness at moment of testing		
Right-handed, n (%)	10 (66.7)	13 (86.7)
Left-handed, n (%)	5 (33.3)	2 (13.3)
Pedometer worn right side, n (%)	9 (60)	15 (100)

BMI, body mass index; RMA-GF, Rivermead Motor Assessment-Gross Function; IQR, interquartile range; FAC, Functional Ambulation Categories; ADL, activity of daily living.

Table 3. Number of steps measured by Yamax Digi-Walker SW-200 Pedometer (YDWP), SenseWear Pro2 Armband (SWP2A) and criterion standard while walking on a flat level surface at two different speeds in stroke and healthy adults.

	Stroke ($N = 14$)					Healthy ($N = 15$)				
	Median	Minimum	Maximum	P25	P75	Median	Minimum	Maximum	P25	P75
Normal walking										
YDWP hip	190	0	355	0	244	188	0	211	170	196
YDWP knee	232	172	389	206	270	190	158	243	178	211
SWP2A right	127	0	297	45	178	124	70	202	81	146
SWP2A left	145	0	375	76	179	93	60	209	82	163
Manual counted	237	172	390	205	308	190	156	214	176	190
Brisk walking										
YDWP hip	171	0	361	2	232	156	9	193	142	169
YDWP knee	218	150	359	193	278	162	132	185	144	176
SWP2A right	177	0	368	84	153	98	40	187	56	141
SWP2A left	146	28	414	102	180	110	24	190	69	145
Manual counted	210	148	356	186	283	156	132	184	142	168

P25–P75, percentile 25 and 75.

the knee and the manually counted number of steps ($r_s \geq 0.89$; $p < 0.01$) in walking activities of the healthy participants. For the stroke group, significant moderate to excellent correlations were found for treadmill walking at 1.5 km/h ($r_s = 0.69$) and walking on a flat level surface at two different speeds ($r_s > 0.95$) between the pedometer worn on the knee and the manually counted steps. When the pedometer was worn on the hip, poor correlations were found in both groups. For the SWP2A, no to little significant agreement was found when results were compared with the manually counted steps, both with the armband worn on the hemiplegic or the non-hemiplegic side.

In Figure 1, the results are plotted to visualize steps measured with the pedometer worn on the knee and the manually counted steps in stroke and healthy participants. Results illustrate that the pedometer worn at the knee measures accurately at different intensities of walking in healthy participants and also in stroke patients at slow walking on a treadmill and at different intensities on a flat level surface. During walking on a treadmill, walking up and down a step and cycling, the pedometer is often undercounting the number of steps (results not shown).

Number of steps measured: reliability

Table 5 shows the test–retest reliability between the steps between the manually counted steps and the steps measured with the pedometer worn on the hip and knee and with both SWP2A (worn on left and right arm). The test–retest reliability during treadmill walking at 1.5 km/h ranged from good to excellent ($0.66 \leq \text{ICCs} \geq 0.98$). The test–retest results found for walking on the treadmill at 3 km/h were categorized as excellent ($0.79 \leq \text{ICCs} \geq 0.97$).

Energy expenditure measured: validity of SWP2A

Correlation coefficients between the ergospiro device and the SWP2A for measuring energy expenditure are presented in Table 4. In general, the results for the measurements taken in lying, sitting and standing show poor to fair correlations. For the other activities, varying results were found in both groups. Only a few participants could fulfill the more strenuous activities. A Bland–Altman plot showed that there was both under- and overestimation in EE measured by the SWP2A compared

Table 4. Spearman correlation coefficient for number of steps and energy expenditure in stroke and healthy participants while executing simulated functional activities.

Number of steps	Stroke					Healthy				
Activity	*n*	SWP2A right	SWP2A left	YDWP hip	YDWP knee	*n*	SWP2A right	SWP2A left	YDWP hip	YDWP knee
Treadmill at 1.5 km/h	12	0.51	0.40	0.38	0.69*	15	−0.08	−0.04	0.21	0.91**
Treadmill at 3 km/h	7	−0.37	−0.52	−0.41	0.64	14	−0.13	−0.21	0.41	0.93**
Treadmill at 3 km/h +5%	5	0.60	0.30	0.90*	0.30	14	0.09	0.29	0.21	0.97**
Step 10 beats/min	14	−0.30	0.08	−0.63*	−0.47	15	0.10	0.17	0.07	0.31
Step 20 beats/min	10	−0.63	−0.78	−0.30	−0.44	15	−0.23	−0.21	−0.50	−0.39
Normal walking 120 m	14	−0.13	−0.23	0.33	0.95**	15	0.46	0.50	0.56*	0.89**
Brisk walking 120 m	14	−0.04	0.46	0.46	0.98**	15	0.51	0.15	0.62*	0.99**

Energy expenditure	Stroke			Healthy	
Activity	*n*	SWP2A right	SWP2A left	*n*	SWP2A right	SWP2A left
Lying down	15	0.56*	0.49	15	0.77**	0.70**
Standing	15	0.79**	0.81**	15	0.66**	0.58**
Sitting	15	0.78**	0.85**	15	0.24	0.41
Treadmill at 1.5 km/h	12	0.01	0.50	15	0.26	0.14
Treadmill at 3 km/h	7	0.75	0.82*	14	0.67**	0.08
Treadmill at 3 km/h +5%	5	0.50	0.70	14	0.84**	0.72**
Step 10 beats/min	14	0.59*	0.48	15	0.63*	0.49
Step 20 beats/min	10	0.29	0.71*	15	0.84**	0.58*
Cycling 30 W	13	0.71**	0.52	15	0.46	−0.29
Cycling 50 W	9	0.70*	0.33	14	0.63*	0.31
Cycling 65 W	7	0.54	0.00	13	0.40	0.01

n, number; SWP2A, Sense Wear Pro 2 Armband; YDWP, Yamax Digi-Walker SW-200 Pedometer.
*$p < 0.05$.
**$p < 0.01$.

to indirect calorimetry (see Figure 2 walking on treadmill at 1.5 km/h, not all data shown).

Energy expenditure measured: reliability of SWP2A

ICCs of parameters during the treadmill measurements ranged from good to excellent ($0.61 \leq \text{ICCs} \geq 0.99$), when not worn on the hemiparetic arm (Table 5). The ICC values found for cycling at 30 and 50 W were found to be excellent ($\text{ICCs} \geq 0.84$), except for the healthy participants at 30 W (ICCs = 0.29–0.52) and 50 W (SWP2A right ICC = 0.59).

Discussion

Based-up on the test–retest reliability results of this study a knee-worn YDWP and SWP2A showed to be reliable devices to measure walking steps in stroke patients and healthy participants. The SWP2A was found to be a reliable instrument to measure energy expenditure in both groups.

This study also assessed the validity of the YDWP and the SWP2A. In general, no valid results were found for the SWP2A in measuring number of steps and energy expenditure in both groups. In stroke patients, the YDWP gave valid results when it was used in specific walking conditions: walking at normal and brisk intensity and at slow walking on the treadmill. Only in healthy participants the pedometer also showed to be valid at higher walking intensities. As has previously been reported, we also found that the YDWP was more valid when the walking speed increased in both groups [23]. An explanation might be that the YDWP is a spring-levered pedometer, which means that a vertical acceleration of the hip/knee is needed to cause contact of the lever arm with the electrical contact [21]. This might explain why pedometers are less valid at slow walking speed. For the stroke patients, we did not find better results when the walking intensity increased on the treadmill. Apparently many of the patients and healthy participants were not used to walk on a treadmill. They held onto the handrails and walked with a different gait pattern than customarily. A primary difference between treadmill walking and walking on a flat level surface is that participants walked on a treadmill more slowly, with shorter strides, and with more time spent in double support [33]. Also vision may impact on gait pattern. When walking on a treadmill participants do not receive the same optic flow as they do when walking overground. This may alter their balance and stability or their perception of where they are on the treadmill or the speed at which they are ambulating [34].

Walking at indoor level surface we noticed their usual gait pattern and also they were allowed to use their walking aid. People with short strides or shuffling gait have less vertical displacement of the area where the pedometer is attached than when walking similar distances using longer strides and smoother gait [15]. A pedometer does not account for asymmetries in gait. This might explain why our results were better in even surface conditions as compared to the treadmill. Here excellent correlation was found with the reference measurement at both walking intensities. Not only walking intensity is a determining factor in pedometer mechanism, also placement of the device is important. We found higher correlations when the pedometer was worn on the knee, rather than on the hip. Also in previous reports a hip-worn pedometer showed limited validity in hemiparetic stroke patients at slow walking speeds [14,35,36]. An explanation given by the research group of Melanson is that accelerations at the hip in stroke patients are often insufficient in magnitude to cause contact of the lever arm with the electrical contact when a spring-levered pedometer is used [21]. At the hip a piezoelectric pedometer is recommended above a spring-levered pedometer at slower gait speeds [21]. A spring-levered pedometer attached to the knee has not yet been studied by other research groups. The unaffected ankle has been recently been described as a good location to measure ambulatory activity in stroke patients [14]. In the present study, the ankle was not preferred as a place to wear

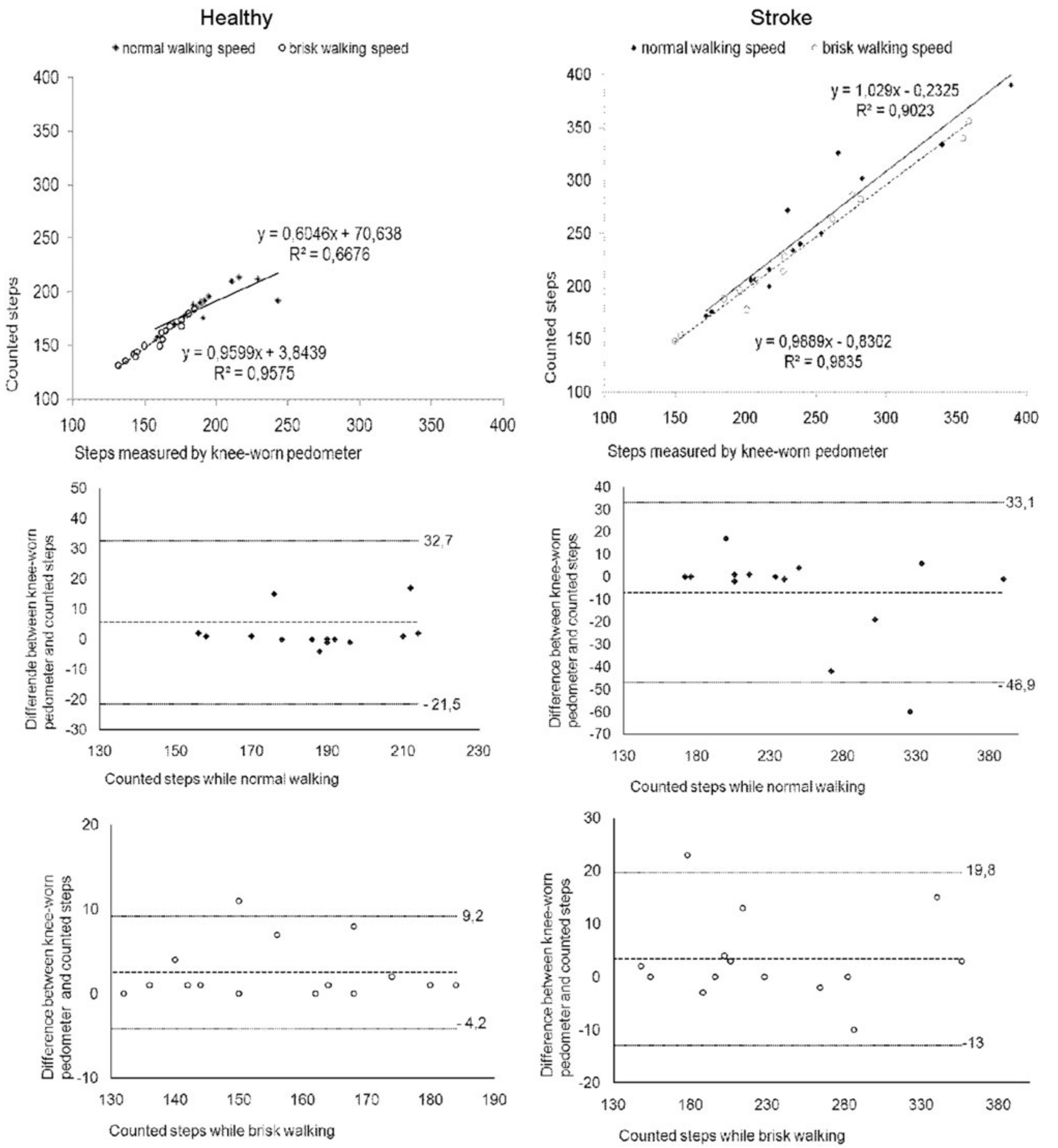

Figure 1. Agreement between the measured steps with the pedometer worn at the knee and the counted steps in healthy participants and stroke patients while walking on ground level surface at two different walking speeds. The solid horizontal lines in Bland–Altman plots represent the 95% limits of agreement corresponding to ±2SD, the horizontal dotted lines represent the mean difference.

a pedometer, because stroke patients often wear high orthopedic shoes, hence uniform attachment of the pedometer could not be guaranteed. Well is know that a pedometer should have attachment to a firm elastic belt, which improves stability and reduces undercounting [37]. We used an elastic belt to attach the YDWP below the knee. This was well tolerated by our participants.

This study further assessed the validity of the SWP2A in measuring number of steps and energy expenditure. As previously reported in other studies, we also assessed that resting energy expenditure measured by the SW2PA correlated poorly to energy expenditure measured by indirect calorimetry in both groups [38]. The Bland–Altman plots showed under- and overestimation of energy expenditure for participants executing simulated functional activities. The manufacturers prescribe the SWP2A to be worn on the right arm in healthy people. There could be a 10% difference in measuring steps and EE between both arms as described by the manufacturers. We could not replicate these differences as the accelerometer was both over- and undercounting at both arms. Also there could be a difference when the SWP2A was placed on the hemiparetic arm versus the unaffected side, because natural arm swing was reduced on the hemiparetic side and handrails were often hold. When arm swing was influenced gait disturbances were noted as is stated in previous studies. Patients and healthy participants took longer and less frequent strides when the

Table 5. Intraclass correlation coefficient in stroke and healthy participants for the number of steps and energy expenditure calculated for the repeated measures.

		Stroke					Healthy				
	Activity	*n*	SWP2A right	SWP2A left	YDWP hip	YDWP knee	*n*	SWP2A right	SWP2A left	YDWP hip	YDWP knee
Steps	Treadmill at 1.5 km/h	12	0.98**	0.89**	0.88**	0.73**	15	0.96**	0.66**	0.79**	0.97**
	Treadmill at 3 km/h	7	0.93**	0.92**	0.96**	0.95**	14	0.79**	0.94**	0.97**	0.94**
EE	Treadmill at 1.5 km/h	12	0.85**	0.76**			15	0.85**	0.73**		
	Treadmill at 3 km/h	7	0.63	0.97**			14	0.61**	0.61**		
	Cycling 30 W	13	0.90**	0.84**			15	0.52*	0.29		
	Cycling 50 W	9	0.95**	0.98**			14	0.59*	0.96**		

EE, energy expenditure; *n,* number (right, right hemi paretic); YDWP, Yamax Digi-Walker SW-200 Pedometer; SWP2A, Sense Wear Pro 2 Armband.
*$p < 0.05$.
**$p < 0.01$.

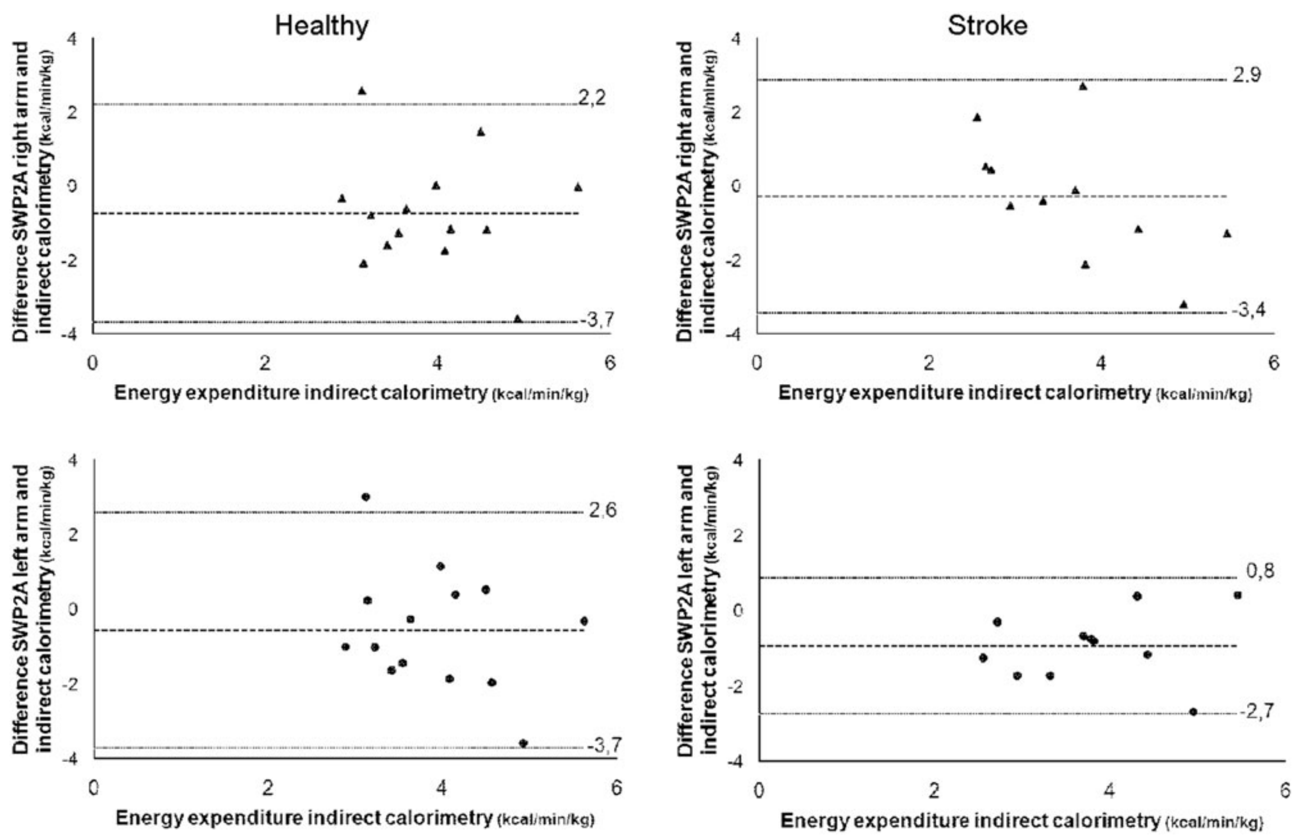

Figure 2. Agreement between the measured energy expenditure with the SWP2A and the criterion standard in healthy participants and stroke patients while walking on a treadmill at 1.5 km/h. Solid horizontal lines represent the 95% limits of agreement corresponding to ±2SD, horizontal dotted lines represent the mean difference.

arms were restrained through holding on to handles when walking on a treadmill at slow speeds [39,40]. Also the device might give better results when the measurements were based on free-living activities instead of simulated functional activities, allowing participants to demonstrate their used walking pattern associated with natural arm swing. The SWP2A may be more useful over a longer period of time registration to monitor daily energy expenditure [41]. Also the device might give better results when the measurements were based on free-living activities instead of simulated functional activities, allowing participants to demonstrate their used walking pattern associated with arm swing.

This study also warrants some critical reflections. A variety of simulated functional activities but of limited duration was chosen to make the protocol feasible for our patients. Simulated functional activities were included, so the measurements could be executed in a lab setting where indirect calorimetry using O_2/CO_2 analysis was possible. Also the protocol was designed to start with relatively easy activities whereas later on exercises became more intense.

A limitation of this study is the intensity of some of the functional activities. Not all participants could perform the more strenuous activities. Therefore generalization of results should be done with caution. Finally the protocol was only feasible for patients with light walking disabilities. In the future, it might be recommendable: (1) to use YDWP and SWP2A in more free-living situations, (2) to include only patients with a hemiparesis or an asymmetrical gait, so more severe disabled patients can be included and (3) to use SWP2A for a period of at least 10 min.

Conclusion

A good test–retest reliability was found for the YDWP and the SWP2A in both groups. This study showed the YDWP to be a valid device in stroke patients, when the pedometer was worn on the non-hemiplegic knee during walking activities except high intensity walking in stroke. In healthy participants, the knee-worn pedometer is valid during all walking activities. Still the pedometer systematically undercounts the number of steps during other short time functional activities. This study could not demonstrate valid measurement of number of steps and energy expenditure in stroke patients using the SWP2A. Further studies are needed to explore valid instruments to measure energy expenditure in stroke.

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Declaration of interest

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